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# EFFECT OF WEAVE ON THE PROPERTIES OF CLOTH[1]

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ABSTRACT

The effect of the weave on the strength, elongation, take-up, tear resistance, fabric assistance, and air permeability of cloth is discussed in this paper. For this purpose a series of 42 cloths were woven from the same cotton yarns in weaves comprising plain, twill, rib, mock leno, basket, sateen, and various combinations of these weaves. The factors which contribute to strength and tear resistance are enumerated and discussed.

Four cloths having high tear resistance were woven for experiments on rubberizing and on doping. The results of these experiments are given and compared with the properties of the gas cell cloth and outer cover cloth which are used in dirigible construction.

CONTENTS



## I. INTRODUCTION

The physical properties and the appearance of cloth depend to a great extent upon the weave. The strength, elongation, take-up, tear resistance, fabric assistance, air permeability, and texture are some of the properties which may be varied by changing the weave. For aeronautical cloths with rigid limits on the weight, the weave is an important means of obtaining some of the desired physical properties.

A cloth of plain weave has in general a greater breaking strength and a lower tear resistance than cloths of the same weight but of different weaves. It also has a greater take-up, higher elongation, and the shortest floats.[2] Not only are high breaking strength and short floats essential in aeronautical cloths, but also high tear resistance and in some cases low elongation.

The purpose of this investigation was to weave a series of cloths from the same cotton yarns in several weaves and to determine the

[1] This investigation was started by Mr. Miller before he left the Bureau of Standards. The cloths were woven by Mr. Porter.

[2] "Float" means the length of a warp or filling yarn between successive interlacings.

effect on the physical properties. A specific object was the determination of the factors requisite for high tear resistance. Four cloths of high tear resistance were woven for experiments on rubberizing and on doping. The results are given and compared with the properties of the untreated cloths and with the properties of the gas cell cloth and outer cover cloth used in dirigible construction.

This work was undertaken by the Bureau of Standards at the request of and with the financial assistance of the Bureau of Aeronautics, Department of Navy. The experiments on rubberizing and doping were carried out by the Goodyear Zeppelin Corporation. Their assistance and cooperation are gratefully acknowledged.

## II. DESCRIPTION OF CLOTHS

The cloths were woven on one loom and with approximately the same tension. The number of threads per inch of cloth in the loom was 90 in the warp and in the filling. The yarn used in the warp was a 57's cotton having a twist of 31 turns per inch (twist multiplier 4). The yarn used in the filling was a 60's cotton having a twist of 21 turns per inch (twist multiplier 2.6). The yarns were of ordinary commercial quality and were bought in the open market.

The weave designs of the cloths, comprising plain, twill, rib, mock leno, basket, sateen, and combinations of these weaves are shown in figures 1, 2, and 3. In drawing the designs the customary convention was employed, namely, a black square indicates that the warp yarn is raised and appears on the upper surface, while a white square indicates that the filling yarn is raised and appears on the upper surface. The vertical columns represent the warp direction while the horizontal rows represents the filling direction. At least one complete pattern of each design is given.

Photomicrographs of the cloths are also shown in figures 1, 2, and 3. They exhibit the surface characteristics of the cloths.

The weaves corresponding to the numbers in figures 1, 2, and 3 are given in table 1. The texture and outstanding surface characteristics are also noted. The cloth of each weave is classified either as firm or sleazy. The cloth is said to be firm if the warp yarns are not easily distorted relative to the filling yarns and sleazy if they are easily distorted. The cloth of each weave is classified either as close or open. The cloth is said to be close if the interstices formed by the interlacing of warp and filling yarns are small and open if they are large. The cloth of each weave is classified either as having long floats or short floats. The cloth is said to have long warp floats if the sum of the number of consecutive filling yarns which a warp yarn passes over plus the number of consecutive filling yarns which it passes under is equal to or greater than 8. A similar convention is used for determining long filling floats. These are purely arbitrary conventions adopted for the purpose of classification.

## III. MEASUREMENT OF PHYSICAL PROPERTIES

All tests were made on material having a normal moisture content, obtained by proper exposure to atmospheric conditions of 65 percent relative humidity and 70° F. Unless otherwise stated, 10 determinations were made for each test. The average result for each test is given in table 1 for the various cloths.

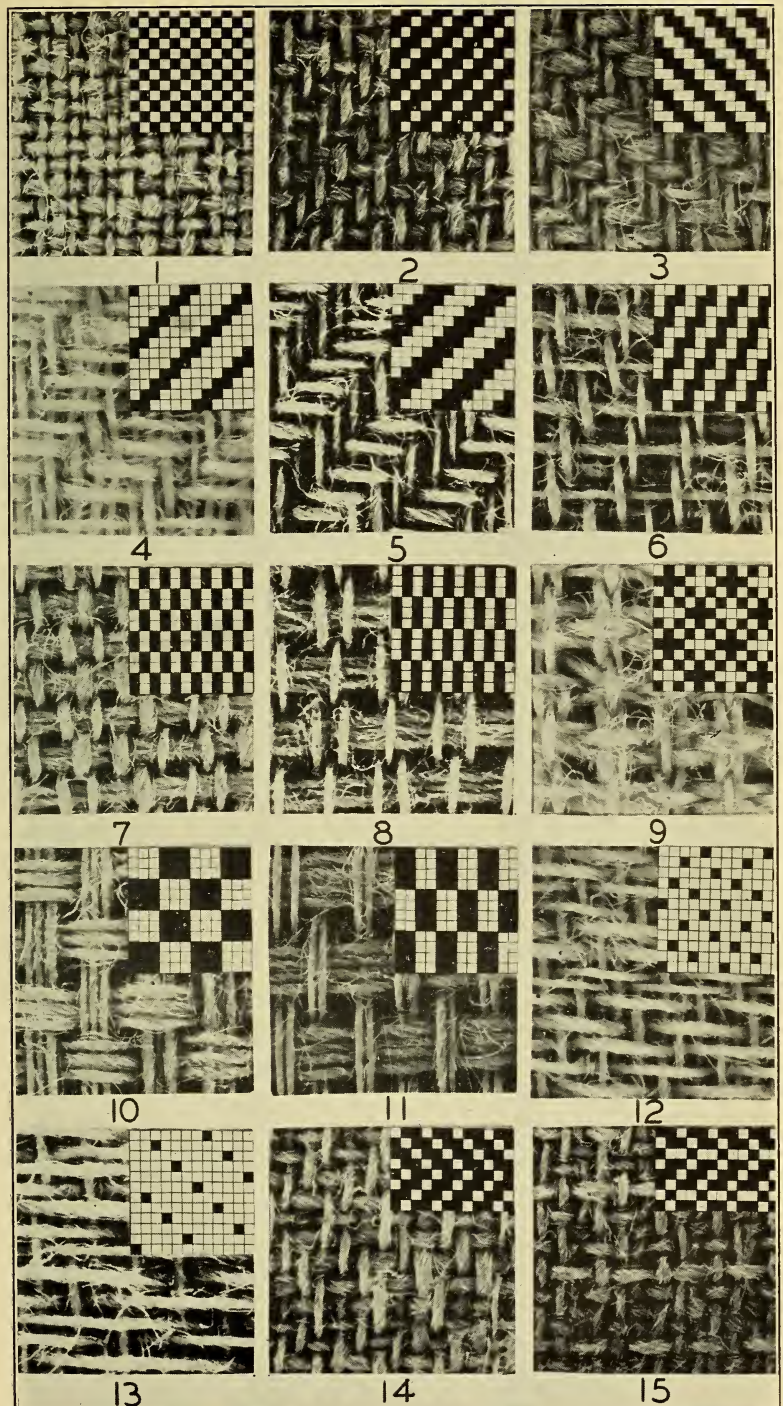


FIGURE 1.—*Weave designs and photomicrographs (×11) of the cloths.*

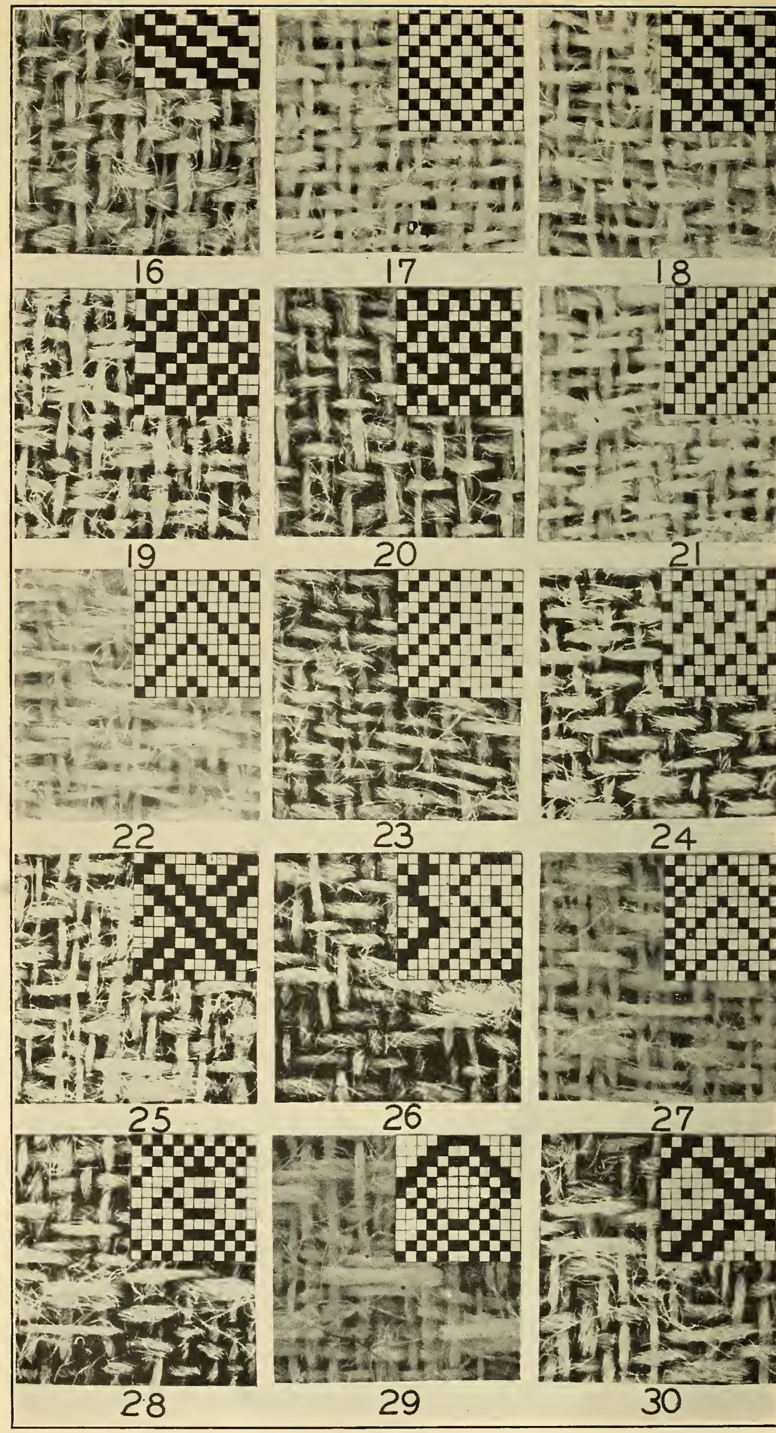


FIGURE 2.—*Weave designs and photomicrographs (×11) of the cloths.*

TABLE 1.—*Effect of weave on the properties of cloths*

| Type of weave | Texture and surface characteristics | | | | | | Specimen no. | Threads per inch | | Weight per square yard [1] | Breaking strength [1] | | Fabric assistance | | Elongation at rupture | | Take-up | | Tear resistance | | Air permeability |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Firm, F | Sleazy, S | Close, C | Open, O | Short floats, s | Long floats, L | | Warp | Filling | | Warp | Filling | Warp | Filling | Warp | Filling | Warp | Filling | Warp | Filling | |
| | | | | | | | | | | *Oz.* | *Lb.* | *Lb.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Lb.* | *Lb.* | |
| Yarn | | | | | | | | | | | [2] 35 | [2] 16 | | | | | | | | | |
| Plain | F | | C | | s | | 1 | 96 | 94 | 2.28 | 40 | 33 | 14 | 106 | 11 | 12 | 8 | 8 | 2.5 | 2 | [3] 192 |
| Twill | F | | C | | s | | 2 | 96 | 92 | 2.23 | 38 | 26 | 9 | 63 | 9 | 12 | 6 | 8 | 3.5 | 2 | 245 |
| Do | F | | C | | s | | 3 | 96 | 91 | 2.22 | 33 | 23 | −6 | 44 | 7 | 11 | 3 | 7 | 4 | 2 | 307 |
| Do | | S | | O | s | | 4 | 96 | 89 | 2.26 | 32 | 20 | −9 | 25 | 5 | 10 | 3 | 7 | 4.5 | 2.5 | 405 |
| Do | | S | | O | s | | 5 | 96 | 90 | 2.22 | 35 | 21 | 0 | 31 | 5 | 11 | 2 | 7 | 4.5 | 2.5 | 400 |
| Do | | S | | O | s | | 6 | 93 | 92 | 2.21 | 42 | 22 | 20 | 38 | 9 | 8 | 5 | 3 | 4.5 | 3 | 405 |
| Rib | F | | | O | s | | 7 | 92 | 93 | 2.19 | 42 | 25 | 20 | 56 | 14 | 7 | 8 | 2 | 3.5 | 3 | 362 |
| Do | | S | | O | s | | 8 | 92 | 92 | 2.22 | 34 | 22 | −3 | 38 | 10 | 7 | 6 | 2 | 4.5 | 3.5 | 451 |
| Mock Leno | F | | | O | s | | 9 | 95 | 92 | 2.29 | 35 | 25 | 0 | 56 | 9 | 11 | 6 | 6 | 4.5 | 3 | 431 |
| Basket | | S | | O | s | | 10 | 94 | 91 | 2.18 | 29 | 19 | −17 | 19 | 5 | 8 | 2 | 6 | 5.5 | 3 | 383 |
| Do | | S | | O | | L | 11 | 93 | 91 | 2.17 | 35 | 22 | 0 | 38 | 7 | 7 | 3 | 3 | 5 | 3.5 | 451 |
| Sateen | | S | C | | s | | 12 | 95 | 90 | 2.22 | 39 | 24 | 11 | 50 | 6 | 10 | 3 | 5 | 4.5 | 3 | 455 |
| Do | | S | | O | | L | 13 | 93 | 90 | 2.21 | 37 | 22 | 6 | 38 | 5 | 8 | 2 | 5 | 6 | 4 | 633 |
| Combination | F | | C | | s | | 14 | 95 | 93 | 2.25 | 38 | 27 | 9 | 69 | 11 | 11 | 6 | 7 | 3.5 | 2.5 | 261 |
| Do | F | | C | | s | | 15 | 96 | 93 | 2.24 | 40 | 30 | 14 | 87 | 10 | 12 | 6 | 7 | 3.5 | 2.5 | 217 |
| Do | F | | C | | s | | 16 | 96 | 92 | 2.23 | 40 | 29 | 14 | 81 | 8 | 13 | 4 | 7 | 4 | 2.5 | 285 |
| Do | F | | C | | s | | 17 | 95 | 92 | 2.22 | 40 | 28 | 14 | 75 | 9 | 10 | 5 | 7 | 3.5 | 3.5 | 263 |
| Do | F | | C | | s | | 18 | 95 | 93 | 2.23 | 39 | 26 | 11 | 63 | 10 | 11 | 5 | 6 | 4 | 2.5 | 313 |
| Do | F | | C | | s | | 19 | 95 | 93 | 2.23 | 40 | 26 | 14 | 63 | 10 | 11 | 5 | 6 | 3.5 | 2.5 | 266 |
| Do | F | | C | | s | | 20 | 96 | 92 | 2.24 | 40 | 28 | 14 | 75 | 9 | 12 | 5 | 8 | 4 | 2.5 | 272 |
| Do | F | | C | | s | | 21 | 96 | 91 | 2.23 | 39 | 27 | 11 | 69 | 8 | 11 | 4 | 6 | 4.5 | 2.5 | 325 |
| Do | F | | C | | s | | 22 | 95 | 92 | 2.22 | 38 | 25 | 9 | 56 | 8 | 10 | 4 | 5 | 4 | 2.5 | 319 |
| Do | F | | C | | s | | 23 | 96 | 91 | 2.23 | 39 | 26 | 11 | 63 | 7 | 11 | 3 | 6 | 4 | 2.5 | 336 |
| Do | F | | C | | s | | 24 | 96 | 91 | 2.26 | 39 | 26 | 11 | 63 | 7 | 11 | 4 | 6 | 4.5 | 2.5 | 325 |
| Do | F | | C | | s | | 25 | 95 | 93 | 2.23 | 39 | 26 | 11 | 63 | 10 | 11 | 5 | 6 | 4 | 2.5 | 307 |
| Do | F | | C | | | L | 26 | 96 | 92 | 2.23 | 39 | 27 | 11 | 69 | 7 | 11 | 4 | 7 | 4 | 2.5 | 378 |

[1] Corrected to 90 by 90 thread count basis.
[2] Breaking strength of 90 threads by the multiple strand method.
[3] Cubic feet per minute per square foot of cloth at a pressure of 0.5 inch of water across the cloth.

TABLE 1.—*Effect of weave on the properties of cloths*—Continued

| Type of weave | Texture and surface characteristics | | | | | | Specimen no. | Threads per inch | | Weight per square yard | Breaking strength [1] | | Fabric assistance | | Elongation of rupture | | Take-up | | Tear resistance | | Air permeability |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Firm, F | Sleazy, S | Close, C | Open, O | Short floats, s | Long floats, L | | Warp | Filling | | Warp | Filling | Warp | Filling | Warp | Filling | Warp | Filling | Warp | Filling | |
| | | | | | | | | | | *Oz.* | *Lb.* | *Lb.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Lb.* | *Lb.* | |
| Do | F | ------ | C | ------ | s | ------ | 27 | 96 | 92 | 2.23 | 40 | 29 | 14 | 81 | 9 | 11 | 5 | 7 | 4 | 2.5 | 290 |
| Do | F | ------ | C | ------ | ------ | L | 28 | 96 | 92 | 2.22 | 40 | 28 | 14 | 75 | 9 | 10 | 4 | 5 | 4 | 2.5 | 331 |
| Do | F | ------ | C | ------ | ------ | L | 29 | 95 | 91 | 2.23 | 39 | 27 | 11 | 69 | 8 | 12 | 4 | 6 | 4 | 2.5 | 341 |
| Do | F | ------ | C | ------ | s | ------ | 30 | 96 | 91 | 2.19 | 33 | 22 | −6 | 38 | 7 | 10 | 4 | 7 | 4 | 2.5 | 336 |
| Do | F | ------ | ------ | O | s | ------ | 31 | 95 | 91 | 2.22 | 33 | 24 | −6 | 50 | 7 | 10 | 4 | 7 | 4.5 | 2.5 | 373 |
| Do | F | ------ | C | ------ | s | ------ | 32 | 96 | 90 | 2.27 | 32 | 25 | −9 | 56 | 7 | 10 | 3 | 6 | 4.5 | 2.5 | 313 |
| Do | F | ------ | C | ------ | s | ------ | 33 | 95 | 92 | 2.22 | 34 | 23 | −3 | 44 | 7 | 10 | 3 | 5 | 4.5 | 2.5 | 373 |
| Do | F | ------ | ------ | O | s | ------ | 34 | 96 | 92 | 2.19 | 34 | 22 | −3 | 38 | 6 | 10 | 3 | 7 | 4.5 | 2.5 | 357 |
| Do | ------ | S | ------ | O | s | ------ | 35 | 94 | 92 | 2.20 | 40 | 26 | 14 | 63 | 9 | 9 | 4 | 4 | 4.5 | 3 | 396 |
| Do | ------ | S | ------ | O | s | ------ | 36 | 96 | 90 | 2.28 | 39 | 26 | 11 | 63 | 7 | 11 | 3 | 7 | 5 | 3 | 550 |
| Do | ------ | S | ------ | O | ------ | L | 37 | 94 | 92 | 2.23 | 30 | 22 | −14 | 38 | 6 | 10 | 3 | 6 | 4.5 | 3 | 414 |
| Do | ------ | S | C | ------ | ------ | L | 38 | 95 | 93 | 2.21 | 39 | 26 | 11 | 63 | 8 | 10 | 4 | 7 | 4 | 2.5 | 367 |
| Do | ------ | S | C | ------ | ------ | L | 39 | 95 | 90 | 2.25 | 32 | 22 | −9 | 38 | 7 | 10 | 3 | 6 | 4.5 | 2.5 | 435 |
| Do | ------ | S | ------ | O | ------ | L | 40 | 95 | 91 | 2.20 | 38 | 26 | 9 | 63 | 6 | 10 | 2 | 6 | 5.5 | 3 | 387 |
| Do | ------ | S | ------ | O | ------ | L | 41 | 93 | 92 | 2.16 | 28 | 20 | −20 | 25 | 6 | 9 | 3 | 4 | 5 | 3 | 514 |
| Do | ------ | S | ------ | O | ------ | L | 42 | 92 | 91 | 2.15 | 33 | 18 | −6 | 13 | 5 | 7 | 2 | 2 | 5.5 | 3.5 | 489 |

[1] Corrected to 90 by 90 thread count basis.
[2] Breaking strength of 90 threads by the multiple strand method.
[3] Cubic feet per minute per square foot of cloth at a pressure of 0.5 inch of water across the cloth.

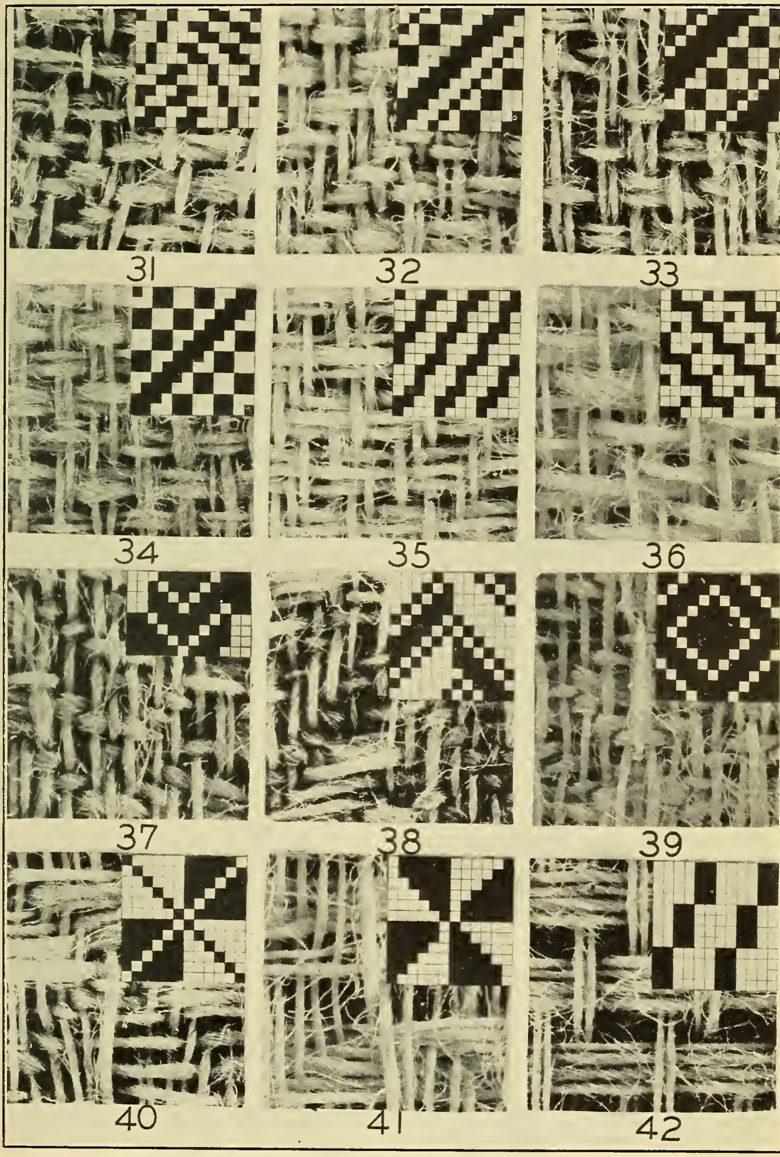


FIGURE 3.—*Weave designs and photomicrographs (× 11) of the cloths.*

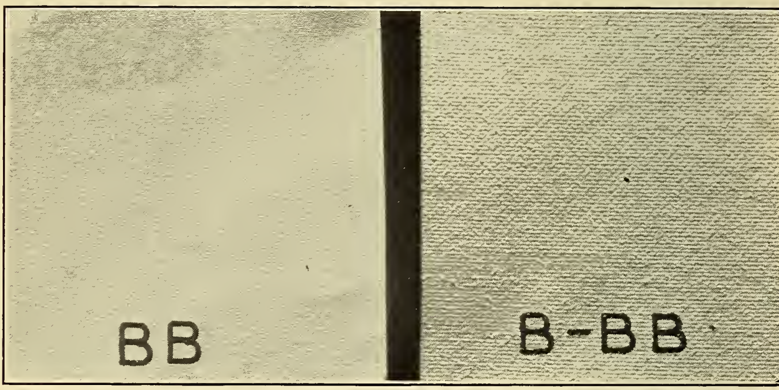


FIGURE 8.—*Surface characteristics of doped cloths.*

BB is regular doped outer cover cloth for dirigibles; B-BB is Bureau of Standards high tear resistance doped cloth.

### 1. THREAD COUNT

Thread-count determinations were made on the specimens which were used for breaking strength. Because of the contraction of the cloth when the tension on it in the loom was released, the number of threads per inch in both the warp and filling is greater than 90. The variation from 90 depends upon the weave and is a maximum for the plain weave.

### 2. WEIGHT

In weight determinations specimens 2 inches square were cut with a die and weighed on an analytical balance. The weight was then expressed in ounces per square yard. The values reported in table 1 have been reduced for comparison to a thread-count basis of 90 threads per inch in warp and filling, respectively.[3] The weights vary from 2.15 to 2.29 ounces per square yard. The variation is due to the different degree of waviness produced in the yarns by the various weaves. The degrees of waviness of the yarns in the various weaves may be seen in figures 1, 2, and 3.

### 3. BREAKING STRENGTH AND ELONGATION

Rectangular specimens, approximately 6 by 1¼ inches, were cut with the long edge either in the warp or in the filling direction as desired. The specimens were then frayed to 1 inch in width and the threads were counted (see section 1).

The tests were made according to the standard procedure on an inclination balance type of machine equipped with an autographic device for drawing the stress-strain curve. The breaking strengths are reported in table 1. For comparison they have been reduced to a thread-count basis of 90 threads per inch. The strengths of 90 warp and of 90 filling yarns tested by the multiple-strand method are also given.[4] The difference between the breaking strength of the cloth on the basis of 90 threads per inch and the breaking strength of 90 strands of yarn expressed as a percentage of the breaking strength of 90 strands of yarn, known as fabric assistance, is also reported in table 1.

The elongation at the breaking load was read directly on the chart from the stress-strain curve. The elongation at rupture in percent is reported in table 1.

### 4. TAKE-UP

Take-up, that is, the percentage decrease of yarn length in the cloth because of the waviness resulting from yarn interlacing, was determined by making ink marks on the cloth 10 inches apart along the warp and filling, respectively. The yarn was then removed from the cloth and the length between the ink marks was measured when just sufficient tension was applied to remove the waviness. If $L$ represents this length in inches, then take-up is given by the expression $(L-10)\frac{100}{L}\cdot$ The results are given in table 1.

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[3] In applying the correction it was assumed that the warp and filling yarns had the same weight.

[4] C. W. Schoffstall and H. A. Hamm, A Multiple Strand Test for Yarns. Bureau of Standards Journal of Research, vol. 2, no. 5, pp. 871-885, 1929.

### 5. TEAR RESISTANCE

Tear resistance determinations were made on specimens 3 inches wide and 6 inches long according to the preferred method of the American Society for Testing Materials.[5] The average result of 5 tests in the warp direction and of 5 tests in the filling direction is reported in table 1 for each cloth.

### 6. AIR PERMEABILITY

Air-permeability determinations were made according to the method described by Schiefer and Best.[6] The average result of 3 tests for each cloth is reported in table 1. It is expressed in cubic feet per

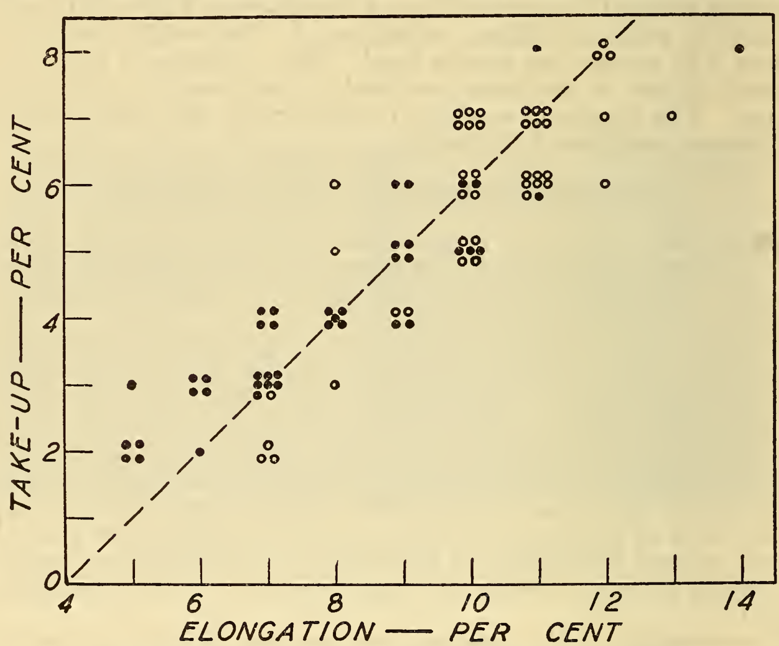


FIGURE 4.—*Correlation between elongation and take-up.*

The points plotted represent the elongation and take-up of the cloths. The values for the warp are indicated by dots and for the filling by circles.

minute per square foot of cloth at a pressure drop of 0.5 inch of water across the cloth.

## IV. DISCUSSION

The data in table 1 show that the weave has a considerable effect upon the properties of the cloths. It is difficult to correlate the properties with the type of weave since the variations of weave for a given type, twill for example, produce almost as great variations as between the types. However, it is worth while to call attention to the correlations between some of the properties.

[5] This is the alternate method described in Proceedings of the American Society for Testing Materials, vol. 32, part I, p. 1007, 1932. It was changed to the preferred method at their annual meeting in Chicago, June 26, 1933.

[6] H. F. Schiefer and A. S. Best, A Portable Instrument for Measuring Air Permeability of Fabrics, B.S. Jour. Research, vol. 6 (RP261), pp. 51–58, 1931.

The elongation of the cloth at rupture, which varies from 5 to 14 percent, appears to vary directly with the take-up (see fig. 4). In general the elongation is about 4 percent greater than the take-up. This increase may be ascribed to the elongation of the yarn.

TABLE 2.—*Effect of texture and surface characteristics on the properties of cloth* [a]

| Texture and surface characteristics | Breaking strength | | Fabric assistance | | Elongation at rupture | | Take-up | | Tear resistance | | Air permeability |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | W | F | W | F | W | F | W | F | W | F | |
| | *Lb.* | *Lb.* | % | % | % | % | | | *Lb.* | *Lb.* | |
| Firm | 37.8 | 26.3 | 8 | 64 | 8.6 | 10.7 | 4.6 | 6.3 | 3.9 | 2.5 | [b] 312 |
| Sleazy | 35.1 | 22.4 | 0 | 40 | 6.6 | 9.0 | 3.1 | 5.0 | 4.8 | 3.0 | 445 |
| Close | 38.3 | 26.8 | 9 | 68 | 8.7 | 11.1 | 4.7 | 6.6 | 3.9 | 2.5 | 292 |
| Open | 35.4 | 22.9 | 1 | 43 | 7.1 | 9.3 | 3.5 | 5.2 | 4.7 | 2.9 | 428 |
| Short floats | 37.3 | 25.2 | 7 | 57 | 8.3 | 10.4 | 4.4 | 6.1 | 4.1 | 2.6 | 339 |
| Long floats | 35.4 | 23.6 | 1 | 48 | 6.7 | 9.5 | 3.1 | 5.2 | 4.8 | 3.0 | 431 |
| Firm, close, short floats | 38.2 | 26.8 | 9 | 68 | 8.7 | 11.1 | 4.7 | 6.7 | 3.9 | 2.5 | 287 |
| Sleazy, open, long floats | 34.0 | 22.2 | −3 | 39 | 6.3 | 8.9 | 2.8 | 3.6 | 5.0 | 3.1 | 462 |

[a] The data of this table are obtained by taking the average of the values reported in table 1 for each classification of texture and surface characteristics.
[b] Cubic feet per minute per square foot of cloth at a pressure drop of 0.5 inch of water across the cloth.

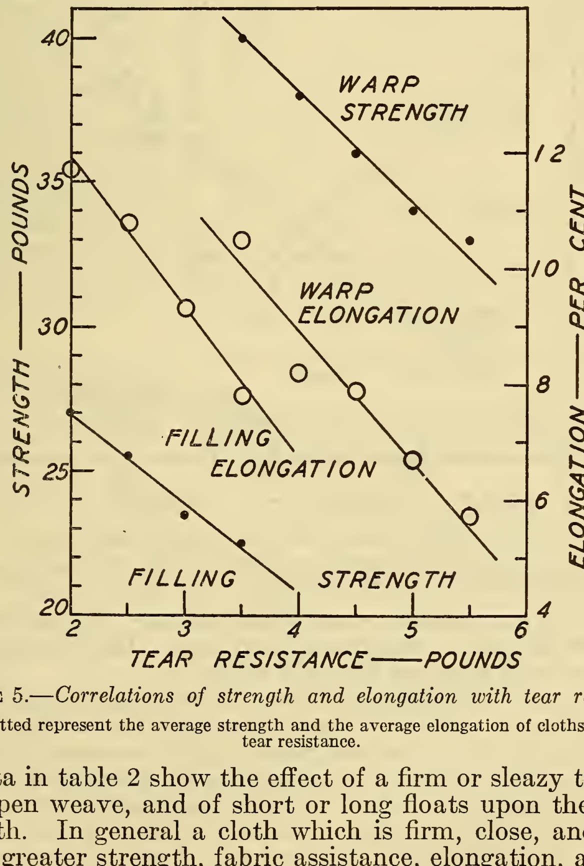


FIGURE 5.—*Correlations of strength and elongation with tear resistance.*

The points plotted represent the average strength and the average elongation of cloths having the same tear resistance.

The data in table 2 show the effect of a firm or sleazy texture, of a close or open weave, and of short or long floats upon the properties of the cloth. In general a cloth which is firm, close, and has short floats has greater strength, fabric assistance, elongation, and take-up and has smaller tear resistance and air permeability than one which is sleazy, open and has long floats.

In general the strength and elongation decrease as the tear resistance is increased. The decrease in average strength and average elongation with increase in tear resistance is shown in figure 5.

It is worth while to discuss briefly some of the factors which contribute to the strength, fabric assistance, and tear resistance of a cloth.

The factors which contribute to the strength of a cloth are (1) the strength of the yarn, (2) the manner of the interlacing of the one set of yarns relative to the other set of yarns, and (3) the twist of the yarn.

It is well known that the strength of a cotton yarn increases with twist up to a certain optimum twist, namely, that which is necessary to practically eliminate fiber slippage. For higher twists the strength decreases because of the torsional stress on the fibers. The filling yarns are weaker than the warp yarns because of the lower twist. This is reflected in the strength of the cloths. The filling strength is less than the warp strength for each weave.

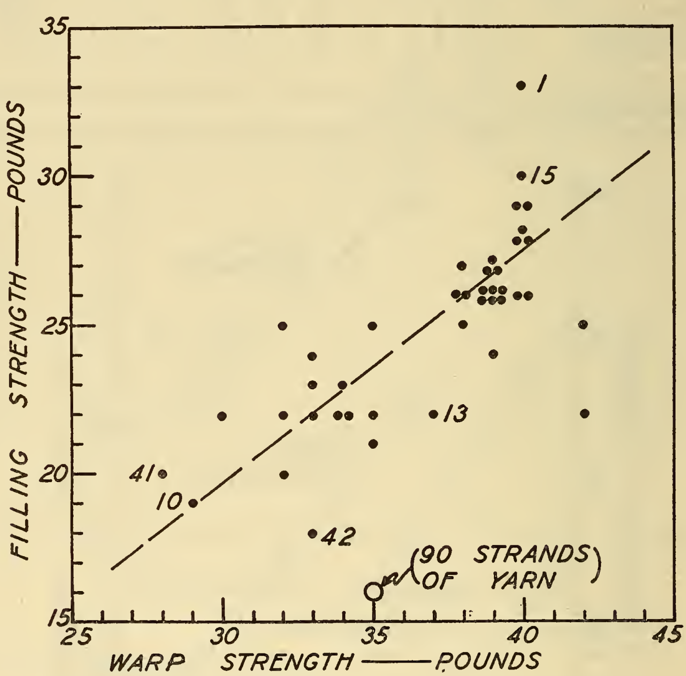


FIGURE 6.—*Correlation between warp and filling strength.*

The points plotted represent the warp and filling strength of the cloths. Weaves nos. 1 and 15 have a large number of thread interlacings compared to weaves nos. 10, 41, and 42.

The warp and filling strengths vary considerably with the weave. This is not due to variation in yarn strength, but to the manner of the interlacing of the two sets of yarn. If the manner of interlacing is regular then the strength increases with the number of interlacings per unit area because the stress is distributed more uniformly. This is shown qualitatively in figure 6 where the filling strength is plotted against the warp strength. Weaves nos. 1 and 15 represent those having a large number of interlacings while weaves nos. 10, 41, and

42 represent those having a small number of interlacings, see figures 1 and 3. Weave no. 13 has the longest floats and the cloth is very sleazy. This figure shows, as expected, that the warp and filling are affected similarly by the manner of interlacings.

The strengths of 90-warp and of 90-filling yarns by the multiple strand method are also plotted in figure 6. It is apparent that the filling strength of each cloth is much greater than the multiple strand strength of 90-filling yarns. This is not true for the warp. In fact for 13 cloths the warp strength is less than the multiple strand strength of 90-warp yarns. It is to be noted that these 13 cloths belong to the class having a small number of thread interlacings. The explanation of these observations is apparent when the twist of the yarn, the number of interlacings, and the chafing action of the reed and harnesses on the warp yarn are taken into consideration.

The filling yarns are weak because of the low twist. They are not weakened by chafing during weaving. Interlacing them with the warp yarns brings the cotton fibers of the yarn into closer contact. This effect increases with the number of interlacings. It is equivalent to increasing the twist in the yarn and produces an apparent increase in the strength of the filling yarn. This apparent increase in yarn strength is actually observed in the filling strength of the cloths and is commonly referred to as fabric assistance.

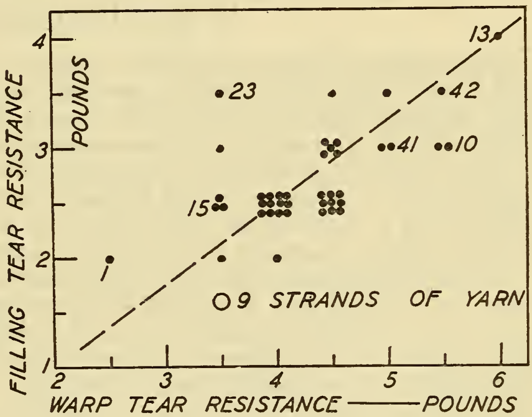


Figure 7.—*Correlation between warp and filling tear resistance.*

The points plotted represent the warp and filling tear resistance of the cloths. Weaves nos. 1 and 15 have a large number of thread interlacings and a firm texture. Weaves nos. 10, 13, 41, and 42 have a small number of thread interlacings and a sleazy texture.

The warp yarns are already relatively strong because of the high twist. They are weakened by chafing during weaving. Because of the high twist in the yarn the fibers are already in close contact with one another so that interlacing them with the filling yarns has relatively little or no effect. In fact, for those weaves having a small number of interlacings, the apparent increase in strength is not sufficient to balance the decrease due to chafing so that the fabric strength is actually less than the yarn strength. This may be referred to as negative fabric assistance. The fabric assistance observed for the weaves having a large number of interlacings is probably chiefly obtained as a result of greater uniformity of stress distribution.

The factors which contribute to the tear resistance of cloth are (1) the strength of the yarn perpendicular to the direction of the tear and (2) the freedom of movement of these yarns in the direction of the tear.

The importance of the first factor is obvious and is shown by the difference between the warp and filling tear (see table 1 and fig. 7).

The second factor contributes to high tear resistance because movement of the yarns, which are being torn, in the direction of the tear

distributes the tearing stress over several adjacent yarns. The greater the freedom of movement the greater will be the number of adjacent yarns which will carry the tearing stress and therefore the greater the tear resistance.

In figure 7 the warp tear is plotted against the filling tear. The warp tear is greater than the filling tear for every weave except no. 23. Weaves nos. 1 and 15 which have a large number of interlacings and a firm texture have the lowest tear resistance, while weaves nos. 10, 13, 41, and 42 which have a small number of thread interlacings, a sleazy texture, and long floats have the highest tear resistance. It is to be noted that the opposite was observed in the consideration of strength. As expected, the warp and filling are affected similarly by the manner of thread interlacing. For comparison in figure 7 there are also plotted the equivalent strengths of 9 warp and of 9 filling yarns; that is, the tear resistance which would be obtained if the tearing stress were uniformly distributed over a cloth width equal to 0.1 inch.

## V. APPLICATION

The results of this investigation indicate the type of weave which will yield cloth having certain specified properties. They also indicate qualitatively the effect of the weave upon the other properties. Cloths which are used for various aeronautical purposes usually have to meet rigid requirements as to weight, strength, permeability, and appearance. For gas cells and for outer cover cloth for dirigibles the cloths must be suitable for rubberizing and doping. The plain weave, which is now used, yields cloth of low tear resistance.

To determine the suitability of high tear resistance cloth for rubberizing and doping and the effect of these treatments upon the properties of the cloths 40 yards of each of 4 cloths of high tear resistance were woven in the Bureau of Standards cotton mill. These cloths were a 3/3 basket, B-HH, and a mock leno, ML-HH, each weighing 2.0 ounces per square yard and a modified mock leno, 40A, weighing 2.2 ounces per square yard to be rubberized similar to gas cell cloth and a 3/3 basket, B-BB, weighing 2.8 ounces per square yard to be doped similar to outer cover cloth for dirigibles.

The yarns used in these cloths were 160/2 spun from Sea Island cotton and were mercerized. They were the strongest yarns commercially obtainable of that size, strength being a factor which yields cloth of high tear resistance. The Bureau cloth 40A was given the regular balloon finish in a commercial finishing plant. Because of the small quantity of cloth and markedly different properties from that of the regular balloon cloth it was badly damaged in places, especially along the selvages, during the finishing process. The Bureau cloths B-HH, ML-HH, and B-BB were not finished but were rubberized and doped as they came from the loom.

These cloths were rubberized, doped, and tested by the Goodyear Zeppelin Corporation. The results are given in table 3. For comparison data are also given for the regular HH gas cell and regular BB outer cover cloths. The data show that the cloths woven at the Bureau of Standards are stronger than the cloths now used. The tear resistances of the Bureau cloths are 2 to 3 times those of the cloths now used. The Bureau cloths retain their superior strength and tear resistance after they are rubberized or doped.

TABLE 3.—*Effect of rubberizing and doping on the properties of cloth*

| Designation | Description of cloth | Weight per sq. yd. | Breaking strength | | Tear resistance | | Gas permeability, liters per square meter in 24 hours |
|---|---|---|---|---|---|---|---|
| | | | Warp | Filling | Warp | Filling | |
| | | *Oz.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | |
| HH | Regular gas cell cloth | 2.0 | [1] 38 | [1] 38 | 3 | 2.7 | |
| B-HH | Bureau of Standards cloth | 2.0 | 47 | 43 | 8.8 | 12.6 | |
| ML-HH | do | 2.0 | 51 | 44 | 6.5 | 6.8 | |
| 40A | do | 2.2 | 49 | 46 | 8.9 | 6.2 | |
| HH | Regular rubberized gas cell cloth | 5.8 | [1] 40 | [1] 40 | 1.8 | 1.8 | Avg. 4.0. Max. 5.0. |
| B-HH | Bureau of Standards rubberized cloth. | 5.7 | 57 | 50 | 7 | 4 | Avg. 5.9. Max. 7.2. Min. 4.1. |
| ML-HH | do | 5.9 | 55 | 47 | 3.5 | 3.5 | Too high for test. |
| 40A | do | 5.8 | 56 | 46 | 11 | 7 | First specimen 4.8. Second specimen 9.5. Third specimen too high for test. |
| BB | Regular outer cover cloth | 2.9 | [1] 60 | [1] 60 | 4.8 | 3.2 | |
| B-BB | Bureau of Standards cloth | 2.8 | 66 | 67 | 9.6 | 9.4 | |
| BB | Regular doped outer cover cloth | [2] 5.5 | 83 | 83 | 2.5 | 2.1 | |
| B-BB | Bureau of Standards doped cloth | 6.2 | 102 | 99 | 4.5 | 4.5 | |

[1] Minimum specified in existing standard.
[2] Nominal specified in existing standard, tolerance +0.4 and −0.2.

It is to be noted, however, that the Bureau cloths ML-HH and 40A after they were rubberized had greater gas permeability than the regular rubberized gas cell cloth. The gas permeability of the Bureau rubberized cloth B-HH is only slightly greater than that of the regular rubberized gas cell cloth. It is probable that if this cloth had received the regular balloon finish including singeing, desizing, tentering, and calendering, that a gas premeability as low as that of the regular rubberized gas cell cloth would have been obtained. Other ways of lowering the gas permeability would be by changing the weave, number of threads per inch, yarn size, and ply of yarn.

The Bureau cloth B-BB after it was doped did not have as smooth a surface as the regular doped outer cover cloth. The surface characteristics of the doped cloths are shown in figure 8. It is probable that a smoother surface would have been obtained if the Bureau cloth B-BB had received the regular balloon finish including singeing, desizing, tentering, and calendering. Other ways of obtaining a smoother surface would be by changing the weave, number of threads per inch, yarn size, and ply of yarn.

## VI. SUMMARY

The effect of the weave on the properties of cloths of the same weight has been studied. In general a cloth which is closely woven, firm, and has a large number of threads interlacings per unit area and short floats has a greater strength, elongation, and take-up and has a lower tear resistance and air permeability than a cloth of the same weight which is loosely woven, sleazy, and has a small number of thread interlacings per unit area and long floats. The strength and elongation decrease as the tear resistance is increased. The factors which contribute to strength and tear resistance have been enumerated and discussed.

The effect of rubberizing and doping on the properties of cloth has been determined. Rubberizing and doping increased the strength and decreased the tear resistance and permeability. A cloth of initially high tear resistance retains its high tear resistance relative to a cloth of initially low tear resistance.

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